Evidence of Atmospheric Contamination on the Measurement of the Spectral Response of the *GMS-5* Water Vapor Channel

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ABSTRACT

The *GMS-5* geostationary satellite carries a channel centered at 6.7 μm for the measurement of upper-tropospheric humidity. This channel's spectral response shows structures that are similar to those shown by the atmospheric transmission. This note shows that these structures probably result from water vapor absorption between the calibration source and the instrument while making the response measurement. A corrected filter is proposed after normalization by the inferred atmospheric transmission. The brightness temperatures computed by a radiative transfer model using the spurious response exhibit a warm bias of about 1 K.

1. Introduction

The Geostationary Meteorological Satellite (*GMS-5*) is one of the geostationary satellites that provides near-continuous coverage of the earth for meteorological and climate purposes. It is operated by the Japan Meteorological Agency (JMA) and is located above the equator at 140°E longitude. The radiometer carries four channels (one in the shortwave, three in the thermal infrared), one of which is designed to observe the upper tropospheric humidity (UTH). The spectral filter is centered on a strong water vapor absorption band around 6.7 μm (or 1500 cm^{-1}). The same absorption band is used on the geostationary Meteosat and Geostationary Operational Environmental (GOES) satellites, as well as on the high-resolution infrared sounder (HIRS) instrument on board the National Oceanic Atmospheric Administration (NOAA) polar-orbiting satellites for the same objective—observing the water vapor in the upper levels of the atmosphere. An accurate knowledge of the instrument filter response is necessary for quantitative analysis of the UTH or assignment of altitudes to wind vectors derived from cloud tracking on the satellite imagery (Schmetz et al. 1995; Soden and Bretherton 1993). The GMS instrument filter was provided by JMA and has been widely distributed, particularly through the International Satellite Cloud Climatology Project (Rossow and Schiffer 1991) documentation. This transmission function is necessary for quantitative analysis of the data, for instance, to simulate the measured signal from a known atmospheric profile.

2. Filter correction

When looking at this filter, we realized that its spectral variations were surprisingly similar to the atmospheric transmission spectral variations (Fig. 1). This led us to suspect some atmospheric absorption contamination while the instrument spectral response was measured. When we inquired about the details, the company that performed the filter measurements reported that the distance between the calibration source and the instrument was about 6 m. Even though this is a rather short path in comparison to a typical atmospheric path for spaceborne remote sensing, small amounts of water vapor could still affect the measured response since the channel resides on a number of strong absorption lines. The spectral band was selected to be sensitive to the rather small amounts of water vapor in the high atmosphere.

To investigate further, we made use of the MODTRAN version 3.7 model (Wang et al. 1996). Our objective was to estimate the absorption along an atmospheric path at surface pressure. The instrument con-

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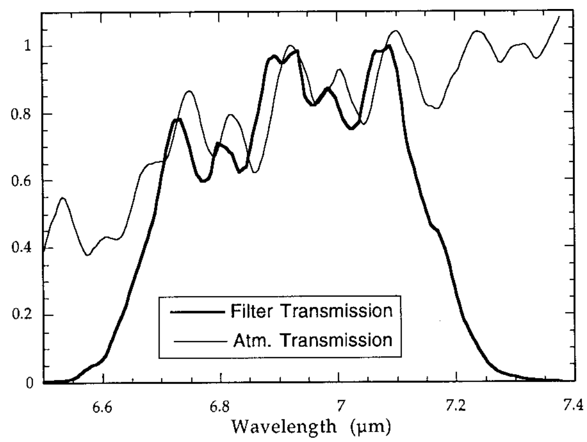

FIG. 1. GMS filter function and atmospheric transmission for a homogeneous path of 6 m, a temperature of 23°C, and a humidity level of 20%. The atmospheric transmission was divided by 0.865 to be 1 at 6.75 μm.

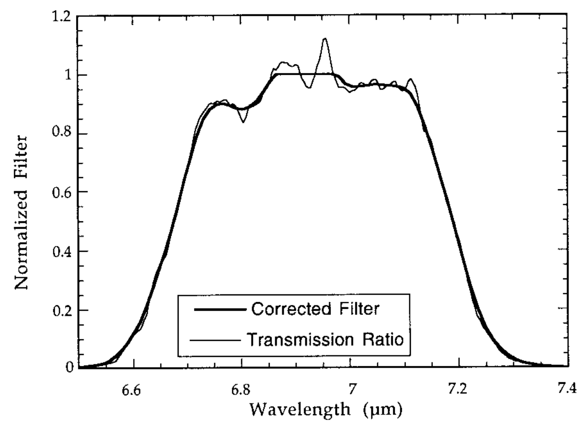

FIG. 2. Ratio of the filter and atmospheric transmissions shown in Fig. 1 after the filter has been spectrally shifted by 0.013 μm and proposed corrected filter.

tractor reported that the temperature during the measurement was 23° ± 5°C, and the humidity as "about 10%" (S. Kurihara 1998, personal communication). The uncertainty on the humidity level is not quantified. The parameter of importance is the total number of molecules (per cm^2) between the calibration source and the instrument. This number is the same for a temperature (humidity) of 23°C (20%) or 28°C (15%). The results below have been obtained with a pathlength of 6 m, a temperature of 23°C, and a relative humidity of 20%. Another combination of parameters (such as a larger temperature and a lower humidity) would give the same results. On the other hand, we have not been able to reproduce the same results as those shown below for a humidity level of 10% and a temperature within the uncertainties.

Another parameter of importance is the spectral resolution. The results of MODTRAN radiative transfer simulations show individual absorption lines that many instruments, with a limited spectral resolution, cannot see. Therefore, the simulation results must be spectrally smoothed at a resolution that is compatible with the instrument used for the filter measurement. After several attempts, we smoothed the atmospheric transmission simulations with a triangular function of half-width 0.040 μm. The actual spectral shape of the source is unknown, and it is a factor of uncertainty for the correction that is attempted below.

Figure 1 shows the filter transmission of the *GMS-5* water vapor channel, together with the result of MODTRAN simulations, as described above. Filter responses are generally normalized by adjusting their maximum value to 1. We have done the same for the result of MODTRAN simulation, by dividing the results by 0.865. The agreement between the two curves in the range of 6.8–7.1 μm clearly demonstrates that the filter response measurement has been contaminated by atmospheric absorption (mostly water vapor). However, there seems to be a slight shift in wavelength between the two curves. The best agreement between the two curves was found for a shift of 0.013 μm, which may be a bias in the wavelength when making the filter measurement.

We now seek a corrected estimate of the *GMS-5* filter transmission. To do that, we divide the original filter by the atmospheric transmission (ratio of the two curves in Fig. 1). However, it is first necessary to shift the filter transmission by 0.013 μm. Figure 2 shows the result of this normalization. The correlation with the atmospheric transmission has been removed, and the instrument response seems to be rather flat between 6.75 and 7.1 μm. There are some high-frequency spectral variations that probably result from the unknown bandpass of the original measurement. A better and more physical estimate of the real GMS instrument filter will be obtained by an additional smoothing of the transmission ratio. The result of this smoothing, which yield the proposed corrected instrument response, is shown in Fig. 2 and the numerical values are reported in Table 1.

3. Outcome

The original spectral response produces larger values when the water vapor absorption is small. Therefore, it is biased toward large transmittance values. Radiative transfer simulations for the original filter function probe lower in the atmosphere than the corrected filter response. We have made simulations for a larger number of atmospheric profiles (TIROS Operational Vertical Sounder Initial Guess Retrieval, or TIGR-3 dataset; Chédin 1985) with the original and the corrected spectral responses. The results show a bias of about 1 K between the two (the simulations with the corrected filter are colder), with a standard deviation of about 0.1 K. This bias results from the correction of the local minimums in the original filter (Fig. 1), which is partly compensated by the spectral shift of the filter. Such a

TABLE 1. Original and corrected filter functions as functions of the wavelength (in μm).

Wavelength	Original	Corrected	Wavelength	Original	Corrected	Wavelength	Original	Corrected
6.466	0.000	0.000	6.755	0.718	0.897	7.072	0.983	0.961
6.477	0.001	0.001	6.768	0.622	0.899	7.085	0.980	0.960
6.488	0.001	0.003	6.780	0.593	0.893	7.099	1.000	0.953
6.499	0.004	0.005	6.792	0.606	0.884	7.112	0.912	0.933
6.511	0.005	0.007	6.804	0.713	0.880	7.125	0.722	0.889
6.522	0.006	0.009	6.817	0.700	0.889	7.139	0.626	0.819
6.533	0.007	0.012	6.829	0.681	0.909	7.152	0.542	0.742
6.545	0.008	0.017	6.841	0.622	0.940	7.166	0.465	0.652
6.556	0.010	0.026	6.854	0.640	0.976	7.180	0.443	0.562
6.567	0.020	0.040	6.866	0.736	1.000	7.193	0.377	0.474
6.579	0.038	0.061	6.879	0.839	1.000	7.207	0.276	0.376
6.590	0.050	0.086	6.891	0.956	1.000	7.221	0.185	0.281
6.602	0.058	0.120	6.904	0.971	1.000	7.235	0.135	0.199
6.613	0.077	0.159	6.916	0.942	1.000	7.249	0.092	0.137
6.625	0.129	0.212	6.929	0.972	1.000	7.263	0.054	0.093
6.637	0.180	0274	6.942	0.985	1.000	7.277	0.032	0.062
6.648	0.223	0.334	6.955	0.842	1.000	7.291	0.022	0.040
6.660	0.296	0.402	6.968	0.817	1.000	7.305	0.017	0.026
6.672	0.355	0.475	6.980	0.845	0.991	7.319	0.011	0.017
6.684	0.417	0.555	6.993	0.876	0.967	7.333	0.008	0.012
6.696	0.486	0.642	7.006	0.842	0.956	7.347	0.005	0.008
6.707	0.585	0.719	7.019	0.776	0.959	7.362	0.004	0.006
6.719	0.697	0.793	7.032	0.747	0.962	7.376	0.003	0.004
6.731	0.779	0.847	7.046	0.771	0.965	7.390	0.000	0.003
6.743	0.781	0.881	7.059	0.893	0.963	7.404	0.000	0.000

difference is not very large, but is significant for quantitative use of the channel. Because of the nonlinear relationship between radiance and brightness temperature in this spectral range, an increase of 1 K corresponds to an increase of 4% on the radiance. Such variation must be accounted for in the instrument calibration. Similarly, a 1-K bias yields a relative error of about 12% on the upper tropospheric humidity (Soden et al. 2000).

Following this work, we investigated the filter responses of other water vapor channels (HIRS-12 on board the NOAA series, *Meteosat-5*, *GOES-8*). These filter responses do not demonstrate significant atmospheric absorption, which indicates that either a drier environment (or a vacuum) or a shorter pathlength was used for the filter characterization.

4. Conclusions

We have shown that the measurement of the spectral response of the *GMS-5* water vapor channel is contaminated by atmospheric absorption. The resulting spectral function is biased toward large atmospheric transmission. We propose a corrected response, which is derived from the original one after normalization by the inferred atmospheric transmission during the measurement. Accounting for this correction yield brightness temperatures colder by about 1 K. Other similar instruments do not show the same spurious response.

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